Exploring comets and asteroids in the 21st century

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There are three primary reasons why the detailed studies of comets and asteroids are of vital importance in the next century. 1.) As the left over bits and pieces from the early solar system formation process, comets and asteroids offer clues as to the chemical mixture from which the planets (including Earth) formed some 4.6 billion years ago. 2.) Comets and asteroids are rich (and easily accessible) resources for the minerals and water that will be necessary to colonize the inner solar system. 3.) For the thousands of comets and asteroids whose trajectories cross that of the Earth, their future motions must be carefully monitored to ensure that none will threaten Earth.

Comets:
As the left over bits and pieces from the outer solar system formation process, comets likely contain the most primitive chemical record of the building blocks of the giant planets. New long-period comets have their origin in the Oort cloud, some 10^4 to 10^5 AU from the Sun and the short-period comets probably originated in the so-called Kuiper belt some 40 - 50 AU from the sun - at Pluto's orbit and just beyond. While long-period comets are very difficult to catch, the nuclei of short-period comets provide very accessible samples of primordial solar nebulae material. However, most short-period comets have spent enough time within a few AUs of the Sun to have undergone chemical and physical alterations in their outer layers. Hence care must be taken in interpreting remote sensing observations of comets in terms of their primordial composition. The emphasis must be on obtaining samples at sufficient depth to reach levels which have escaped alteration due to cosmic ray and thermal wave effects.

Asteroids:
As comets are likely to be the debris from the outer solar system formation process, asteroids are thought to be the building blocks remaining from the formation of the inner solar system's planets, including our Earth. We have detailed analyses of many types of meteorites so there are many clues as to the chemical composition of asteroids. The central problem with asteroid studies is that without in situ investigations of the composition of several different types of asteroids, links cannot be accurately forged between the meteorite types in the Earth's laboratories and asteroid types in space. For example, it is well known that the most common meteorite type, the ordinary chondrites, appears to be nearly absent in the asteroid belt, while the inferred composition of the most common near-Earth and inner-belt asteroid, the S-type, appear very rarely in meteorite collections. A suggested resolution to this enigma is that asteroid spectral characteristics differ from those of pulverized meteorites of the same composition due to hypothetical "space weathering" of the asteroid's regolith. Surface and sub-surface chemical analyses of an S-type asteroid would define the relationship between the S-type asteroids and the

ordinary chondrite meteorites. If parent asteroids of a given spectral type could be uniquely linked to various well-studied meteorites, the detailed chemical composition of newly discovered asteroids could be inferred from ground-based observations of their spectral characteristics.

In terms of their structures, comets and asteroids are likely to run the gamut from fragile popcorn-like material to immense slabs of stainless steel. In addition, some asteroids are almost certainly dormant or de-volatilized comets. Comets and asteroids are widely diverse in their compositions, structures and their spectral characteristics.

The science objectives for in situ missions to comets and asteroids are similar. The primary scientific objectives for these objects are listed below together with the measurements necessary to address these objectives.

a.) In order to obtain the critically important information on the object's composition, the elemental, isotopic, and mineralogical makeup of unaltered materials must be examined. For asteroids, materials just below the surface layer should be examined but for comets, the unaltered material may lie well below the surface. These objectives can be met via sub-surface sample return analysis or by using in situ alpha/x-ray spectrometers or gamma ray and x-ray spectrometers attached to burrowing devices.

b.) To understand how comets and asteroids formed, to assess their suitability for mining their volatiles (including water) and minerals, and to better deal with the deflection of Earth threatening objects, the bulk density and interior structures of various comets and asteroids must be determined. This objective can be met with radio science (tracking data) to determine the object's mass together with imaging and/or lidar data to determine its shape and volume. The bulk density is then determined by dividing the mass by the volume. Burrowing devices carrying sample analyses equipment may be required to reach unaltered subsurface materials below cometary surfaces and to characterize the interior structure of both comets and asteroids. For example, without diagnostic subsurface measurements, the low bulk density (1.3 g/cm^3) of asteroid Mathilde could be due to either a uniform, low-density material or to dense chunks of rock held loosely together with numerous voids (rubble pile).

c.) Efforts should be made to characterize each mission target (asteroid or comet) as to its size, shape, spin state, and surface features. For comets, an effort should be made to examine the surface changes that take place as functions of time and orbital position. Imaging cameras, lidars, and IR spectrometers would be used to address these science objectives.

d.) Since comets and asteroids are likely to be widely diverse in their compositions, surface characteristics and interior structures, efforts should be made to study as many examples as possible.